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**Research Paper
RM-251**

Effects of Weather and Physiographic Conditions on Temperature and Humidity in Subalpine Watersheds of the Fraser Experimental Forest

Merrill R. Kaufmann

Dedication

This paper is dedicated to George Wheatley, who served as a Forest Service technician at the Fraser Experimental Forest for 16 years. His persistent attention to detail, often under the harsh winter conditions of the Rocky Mountains, led to the development of climatic and hydrologic records of outstandingly good quality during his tenure.

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Abstract

Air temperatures were observed at upper elevation and valley weather stations in the subalpine forest zone of the central Rocky Mountains, and canopy temperatures in subalpine watersheds were measured with an infrared thermometer on board a helicopter. During most of the daylight hours, upper elevation air and canopy temperatures were similar to air temperature at a centrally located valley weather station after the valley temperatures were adjusted for a standard adiabatic effect of $-0.0098°C \cdot m^{-1}$. However, clouds and thunderstorm activity introduced considerable local variation in canopy temperature. Slope and aspect had little effect on canopy temperature. Cold air drainage reduced nocturnal valley air temperatures by about 7°C after adjusting for adiabatic effects.

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

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Modeling Implications

The ability to model local differences in temperature and humidity in mountainous regions has considerable appeal for use in process models involving forest consumptive water use, watershed hydrology, tree growth, and air quality. To satisfy this modeling need, this study examined the effects of elevation on air temperature and ambient absolute humidity, and the effects of elevation, slope, aspect, and local weather disturbances on canopy temperature.

Mean hourly air temperature, measured at a valley weather station located at the convergence of several watersheds, was similar to mean air or canopy temperature at higher elevations, up to 8 km away, during most of the daylight hours, after a standard correction for adiabatic effects ($-0.0098°C \cdot m^{-1}$). However, cold air drainage cooled the valley weather station about 7° C during most of the night and early morning. Cold air drainage transported upper-elevation air to the valley weather station, and the minimum ambient absolute humidity measured during the morning was similar to the upper-elevation absolute humidity throughout the day. During summer months, ambient absolute humidity increased diurnally at the valley floor but not at the upper elevations.

Canopy temperature, measured with an infrared thermometer on board a helicopter, also was influenced by elevation, but differences in direct beam irradiance associated with slope and aspect had almost no effect on canopy temperature. Canopy temperature was 4° to 5° C cooler under clouds than under clear sky. However, large local differences in canopy temperature (up to 10° C or more) were observed during thundershower activity. These large local variations preclude the use of off-site weather data for making accurate instantaneous estimates of canopy temperature.

The effect of elevation and cold air drainage and the lack of effect of slope, aspect, and irradiance on canopy temperatures during the summer months probably occurs throughout the central Rocky Mountains, an area dominated by a fairly stable high pressure system.

Introduction

Weather conditions in mountainous regions generally vary over time and space. In the central Rocky Mountains, regional weather phenomena are related primarily to synoptic activity, while localized phenomena are related to convective thunderstorm activity and thermally-induced downslope and upslope air movement.

Knowledge of air temperature and humidity in mountainous areas is becoming increasingly important. For example, calculations of consumptive water use by forests in subalpine watersheds require knowledge of temperature and ambient absolute humidity for each forest stand (Kaufmann 1984a and 1984b). Also, physiographic variables, such as slope, aspect, and elevation, are thought to influence tree regeneration and growth, but the role of site and microclimate effects is difficult to assess without direct knowledge of microclimate conditions.

Attempts to predict temperature in mountainous topography generally have been limited to fairly large-scale situations. For example, Campbell (1972) attempted to predict temperatures in a watershed, using weather records collected at an airport 96 km away. More recently, Running and Hungerford (1983) examined temperature and relative humidity in Montana forests, using airport weather records collected about 32 km away. Their calculations included an empirical adjustment of up to ±2° C to account for possible effects of slope and aspect on temperature.

Weather data have been collected for many years at several locations on the Fraser Experimental Forest in the central Rocky Mountains. In addition, canopy temperature data were collected with an infrared thermometer mounted on board a helicopter flown over the Forest. Together, these data permit an evaluation of long-term and short-term temperature and humidity variation in relation to elevation, slope, aspect, and time of day. This paper evaluates the use of data from a centrally located weather station for predicting air and canopy temperature and ambient absolute humidity in nearby subalpine watersheds in the central Rocky Mountains.

Study Area and Methods

Long-term Weather Records

Studies were conducted at the Fraser Experimental Forest (FEF) 8 km southwest of Fraser, Colo. (Alexander and Watkins 1977). The FEF Headquarters area is at the convergence of the main St. Louis Creek drainage and several smaller drainages (fig. 1), at 2758 m elevation. With the exception of the northeast portions of the main St. Louis Creek drainage, the entire boundary of the 93 km^2 St. Louis Creek watershed is above treeline, at elevations ranging from 3500 to 3900 m.

Permanent weather stations have existed for several decades at the FEF Headquarters area and at the Wind

Tower (WT) site (fig. 1). In 1977, an additional temporary weather station was installed in the Deadhorse watershed (DH in fig. 1). The DH and WT weather stations are at elevations of 3060 m and 3230 m, respectively. The DH station is beneath a mature Engelmann spruce-subalpine fir stand, about 100 m below the ridge separating the Deadhorse and West St. Louis Creek drainages. The WT weather station is in a clearcut, about 20 m from a mature lodgepole pine stand, and about 40 m east of the ridge separating the East St. Louis and Fool Creek watersheds. The FEF Headquarters station is in a 25° opening (originally 30°, measured from the vertical) of a second-growth lodgepole pine stand. Each weather station is equipped with a hygrothermograph and air temperature and maximum-minimum thermometers enclosed in a standard weather shelter. The hygrothermographs were calibrated periodically, using standard techniques to assure that equal conditions yielded similar readings. Weekly minimum hygrothermograph temperatures compared favorably with those observed with the maximum-minimum thermometer, and saturated conditions consistently yielded relative humidities of 100 percent. However, relative humidities measured with hygrothermographs having hair elements are known to be variable, and this limitation in the data is recognized.

Weather records for 1978 through 1981 were used for analyses. For Wednesday of each week of each year, temperature and relative humidity were determined at 2-hour intervals from hygrothermograph records. Data sampling was limited to a 4-year period, because earlier data were not available at the DH weather station. These years appeared to be representative of the range of conditions typically encountered during the past 15 to 20 years. Analyses of weather station data were conducted using the means of the 4-year period for each observation time. The objective of these analyses was to determine if temperature and humidity at the higher elevation sites was systematically related to conditions at the FEF Headquarters. Use of a fairly short period of 4 years is acceptable, because the main objective addresses differences among sites, not long-term characterization of weather conditions.

Fig. 1.—Map of the Fraser Experimental Forest showing the major watersheds and locations of weather stations.

Canopy Temperature

In 1982, an infrared (IR) thermometer (Model 210, Everest Interscience[2]), mounted on a helicopter, was used to measure canopy temperatures. The IR thermometer was mounted on a camera pod which extended outside a helicopter door opening. The camera pod also supported a color video camera. Control and recording equipment was placed inside the cabin. The video tape image included time and date. A battery-powered strip chart analog recorder was used to record output from the IR thermometer. The color video image and time recorded on tape were used along with the strip chart IR temperature record to determine IR temperature estimates for specific locations on the ground. The IR thermometer had a pass band of 7 to 16 μm and was operated using an emissivity of 0.98.

The IR thermometer and color video image data were collected on 4 flights per day, on July 13 and August 17, 1982, beginning shortly after sunrise and ending before sunset. These days were typical for the FEF area, beginning with clear weather, followed by partial or complete cloudiness and scattered showers during mid-afternoon.

A similar flight path about 50 km long was followed for each flight. The flight path included transects, in order, across East St. Louis Creek, Fool Creek, lower St. Louis Creek, West St. Louis Creek, Lexen Creek, and Deadhorse Creek (fig. 1). The helicopter was flown at a velocity of about 60 $km \cdot h^{-1}$ and an altitude of about 500 m above the ridges separating the watersheds. The IR thermometer field of view was 20°, yielding a canopy sampling area about 150–225 m in diameter. Slope, aspect, and elevation were determined for 39 specific locations along the flight path, using topographic maps. In addition, the profile of the horizon was determined for each location. These measurements permitted the calculation of direct beam solar irradiance for each site for each flight, with corrections for situations when an intervening ridge obscured the sun (Kaufmann and Weatherred 1982).

Results

Long-term Temperature and Absolute Humidity Relationships

Four-year mean diurnal temperature patterns for each of the weather stations are shown in figure 2 for

[2]Use of trade names is for the convenience of the reader and is not meant to imply preference or endorsement of USDA to the exclusion of any other product that may be suitable.

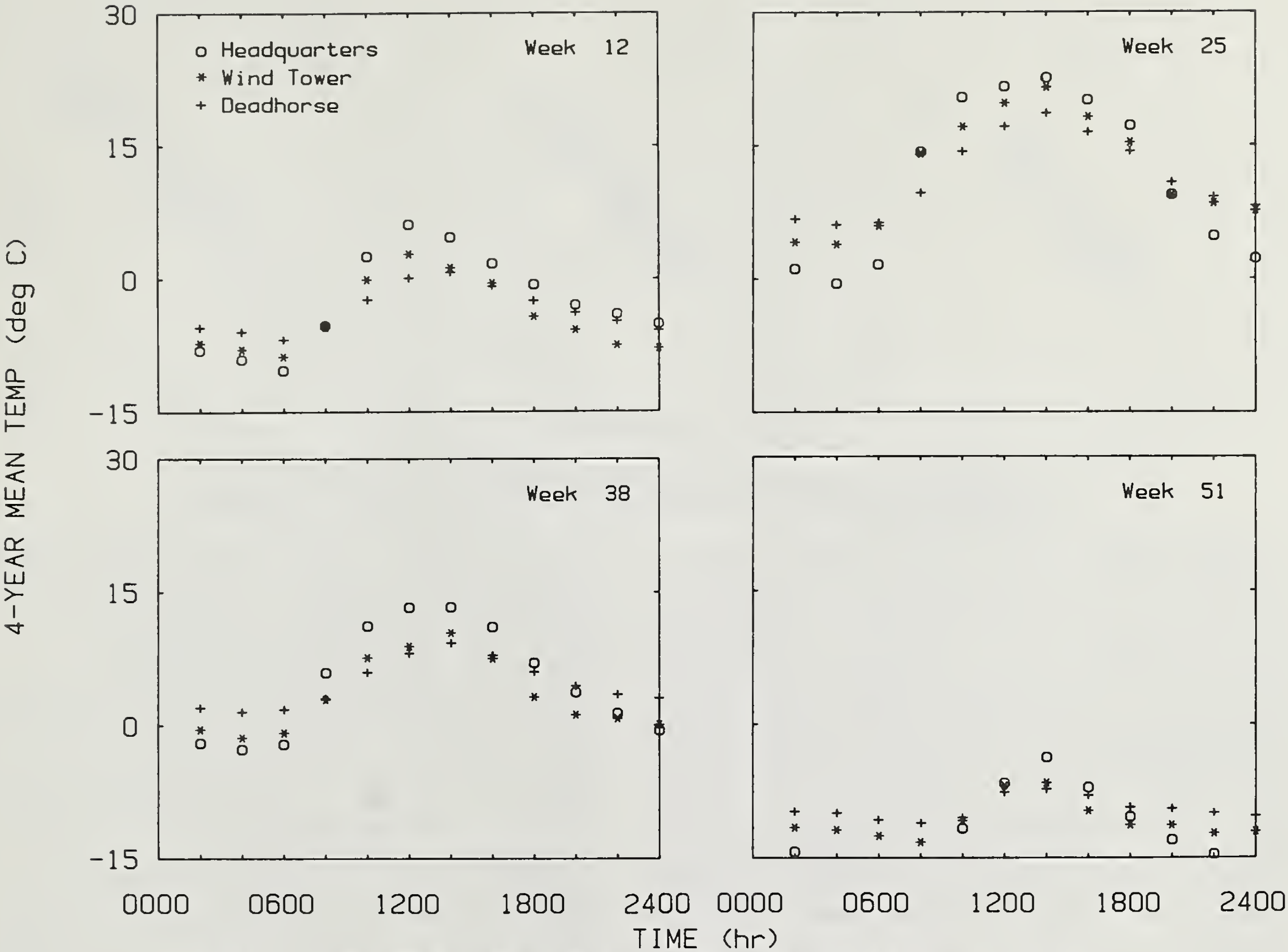

Fig. 2.—Four-year mean diurnal air temperature at FEF Headquarters, Wind Tower, and Deadhorse weather stations. Minimum temperatures at the FEF Headquarters during week 51 (data not shown) were below −15° C.

the weeks corresponding to the solar equinoxes and solstices. During midday, temperature at the FEF Headquarters was consistently higher than at the other two stations. The WT temperature was frequently higher than the DH temperature, even though the WT site was at a higher elevation. The DH station was beneath the forest canopy on a north exposure, which probably resulted in slightly cooler midday temperatures at the instrument shelter near the ground.

At night, air temperature was lower at the FEF Headquarters station than at the higher elevation stations as a result of cold air drainage. This pattern was consistent throughout the year. A careful examination of all the weekly data revealed that the cold air drainage effect developed 1 to 5 hours after sunset and lasted until 1.5 to 3.5 hours after sunrise.

On that basis, data were sorted for a comparison of DH and WT air temperature with FEF Headquarters air temperature (fig. 3). Nocturnal values are for temperatures observed later than 5 hours after sunset and earlier than 1.5 hours after sunrise. Transition values were observed 1.5 to 3.5 hours after sunrise and 1 to 5 hours after sunset. Diurnal values include observations from 3.5 hours after sunrise to 1 hour after sunset. The FEF Headquarters temperatures were adjusted for dry adiabatic lapse rate effects at a standard rate of $-0.0098° \cdot m^{-1}$ (Barry 1981). The adiabatic correction accounts for temperature changes of an air mass which expands or shrinks as a result of a change in elevation. Thus the DH temperatures were plotted against [FEF Headquarters temperatures minus 2.96° C], and WT temperatures were plotted against [FEF Headquarters temperatures minus 4.63° C].

After adjusting for adiabatic effects, nocturnal temperatures at the WT or DH weather stations were consistently higher than observed at the FEF Headquarters station (fig. 3, left). The cold air drainage effect reduced the FEF Headquarters temperature an average of about 7° C. During the daytime, however, the temperatures agreed very well after adjusting for adiabatic effects (fig. 3, right). Slightly higher diurnal WT and DH temperatures at low FEF Headquarters temperatures probably reflect a persistent valley temperature inversion or a cold air drainage effect during the daytime in winter months, when the sun angle is very low. Temperatures during the transition periods were variable and tended to fall between the nocturnal and diurnal values (fig. 3, center).

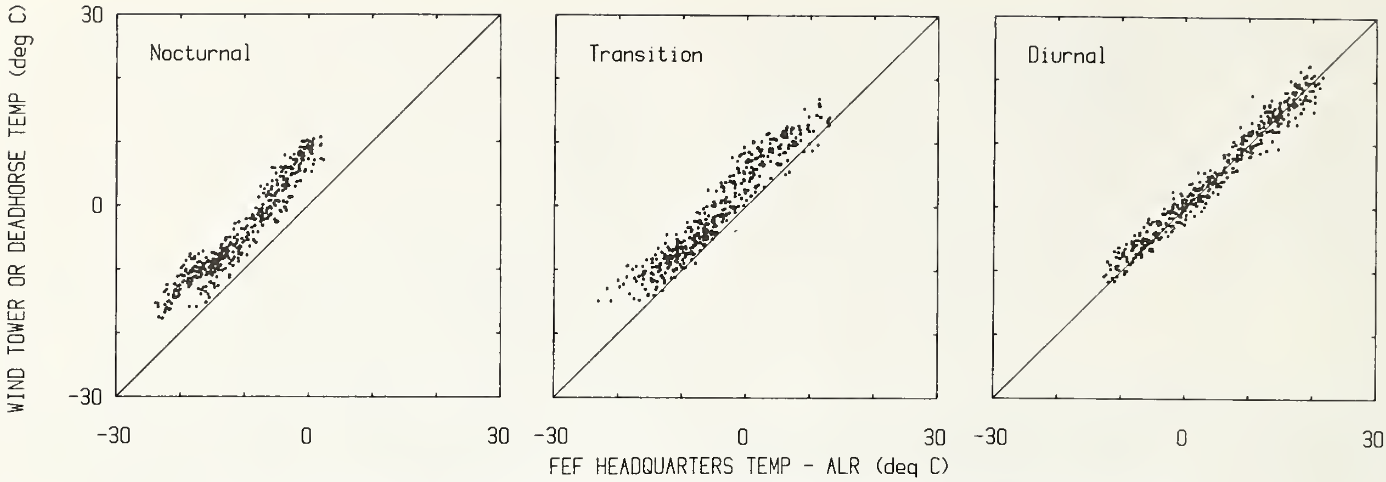

Fig. 3.—Comparision of Wind Tower and Deadhorse weather station temperatures with FEF Headquarters temperatures. The Headquarters temperatures were adjusted for adiabatic lapse rate ($-0.0098°\ C \cdot m^{-1}$).

Ambient absolute humidity was determined from air temperature and relative humidity at each weather station. Four-year mean diurnal patterns of ambient absolute humidity are shown in figure 4 for the same weeks used in figure 2. Two patterns were apparent in the data. First, during midday for weeks 12 to 42, the ambient absolute humidity at the FEF Headquarters was consistently higher than the nocturnal or early morning value. The slight midday increase for the WT station seen in weeks 25 and 38 was observed in only several cases. Second, the minimum ambient absolute humidity observed in the morning at the FEF Headquarters was similar to the ambient absolute humidity observed throughout the day at the higher elevation weather stations.

A comparison of the WT and DH ambient absolute humidities throughout the day and night with the minimum morning ambient humidity observed at the FEF Headquarters is shown in figure 5. Most upper elevation absolute humidity observations (means of four years) were within 1.5 $\mu g \cdot cm^{-3}$ of the minimum FEF Headquarters value. However, when the daytime and nighttime ambient absolute humidites at the FEF Headquarters were compared with the Headquarters morning minimum (fig. 6), observations were stratified during weeks 12 to 42, with diurnal values (0800 to 2000 hr) being as much as 5 $\mu g \cdot cm^{-3}$ higher than the minimum. Ambient absolute humidities below the minimum morning value in figure 6 were observed in the evening. The annual pattern of the minimum morning ambient absolute humidity at the FEF Headquarters is shown in figure 7. Minimum ambient humidities were above 5 $\mu g \cdot cm^{-3}$ in the summer and about 2.5 $\mu g \cdot cm^{-3}$ in the winter.

Canopy Temperature

IR temperatures of the forest canopy during an early morning flight on August 17, 1982, are shown in figure 8. At the beginning of the flight, the solar elevation and azimuth were 22° and 91°, respectively. By the end of the flight, the values had increased slightly to 28° and 96°. Thus the steeper west-facing slopes (e.g., the eastern part of the East St. Louis Creek watershed) were still in shade, but other slopes were already in sunlight. Canopy temperatures for this flight ranged from 4° C in upper East St. Louis Creek to 15.5° C on slopes at lower elevations just north of the FEF Headquarters.

Under the clear conditions encountered for the flight reported in figure 8, the situation was potentially suitable for producing a canopy temperature difference within the East St. Louis Creek drainage caused by differences in irradiance, because the west-facing slopes were still shaded, while the east-facing slopes were receiving direct sunlight. The effect of direct beam irradiance was examined for various drainages, for each flight, by calculating the difference between site temperature within a drainage and the FEF Headquarters weather station air temperature, adjusted for adiabatic lapse rate. This difference was compared with the difference in potential direct beam solar irradiance between the site and FEF Headquarters. A potential direct beam irradiance of 0.0 was assigned in the shade, and an irradiance of 1.0 was assigned when the sun was normal to the surface (Kaufmann and Weatherred 1982).

A comparison of temperature and irradiance differences for the East St. Louis Creek data of figure 8 is shown in figure 9. The FEF Headquarters weather station temperature was 11° C when the East St. Louis Creek data were collected. After adjusting for adiabatic effects, the temperature differences were less than 4° C. On this particular flight, site temperature in East St. Louis Creek was slightly affected by direct beam irradiance ($Y = 1.6 + 2.4X$, $r^2 = 0.44$, where Y is the temperature difference and X is the relative irradiance). In general, however, no significant effect of irradiance on temperature was observed. For almost all flights and drainages, the canopy temperature of stands on different slopes and aspects was unrelated to relative instantaneous direct beam irradiance.

In some instances, local canopy temperatures differed greatly among areas of the FEF sampled in the helicopter IR study. IR temperatures shown in figure 10 were measured during a period when a cold thunderstorm system passed from west to east. IR temperature

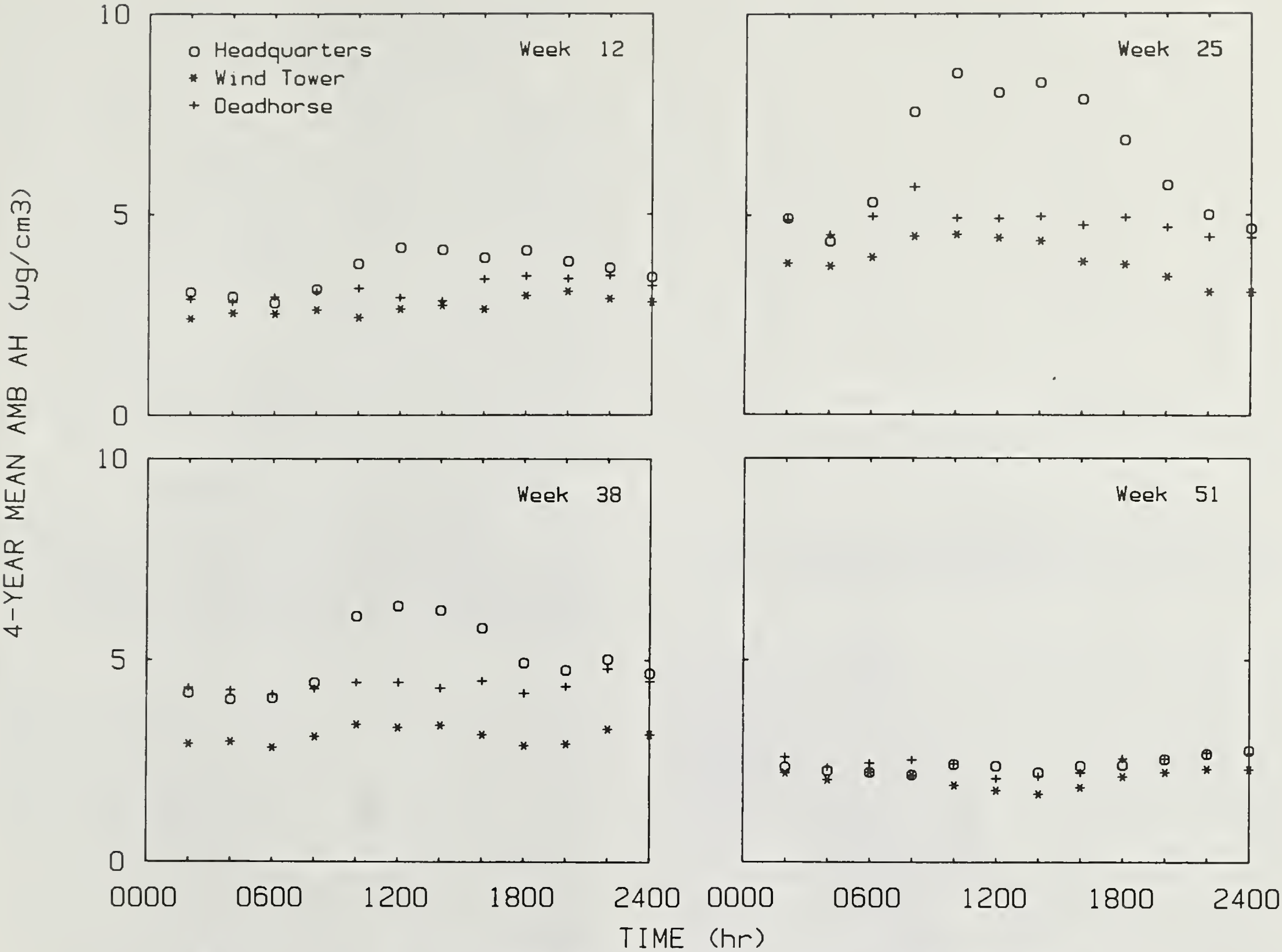

Fig. 4.—Four-year mean diurnal ambient absolute humidity at FEF Headquarters, Wind Tower, and Deadhorse weather stations ($1\ \mu g \cdot cm^{-3} = 1\ g \cdot m^{-3}$).

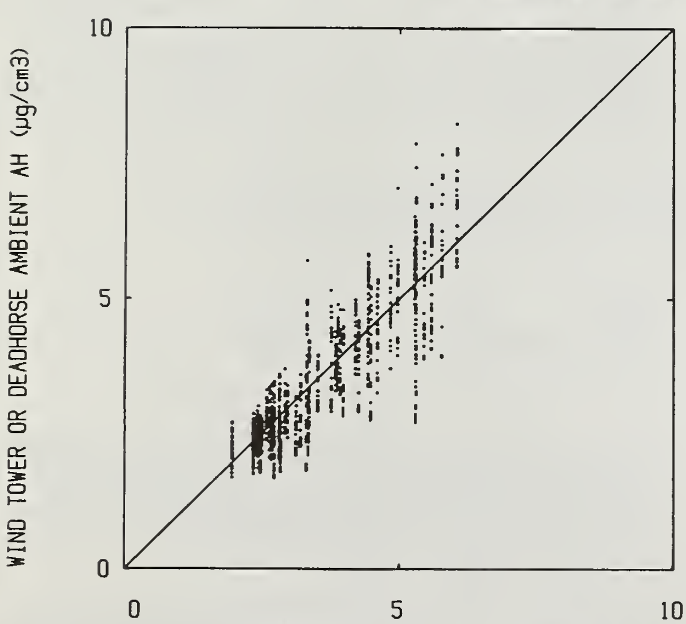

Fig. 5.—Comparison of Wind Tower and Deadhorse weather station ambient absolute humidities with the morning minimum FEF Headquarters ambient absolute humidity.

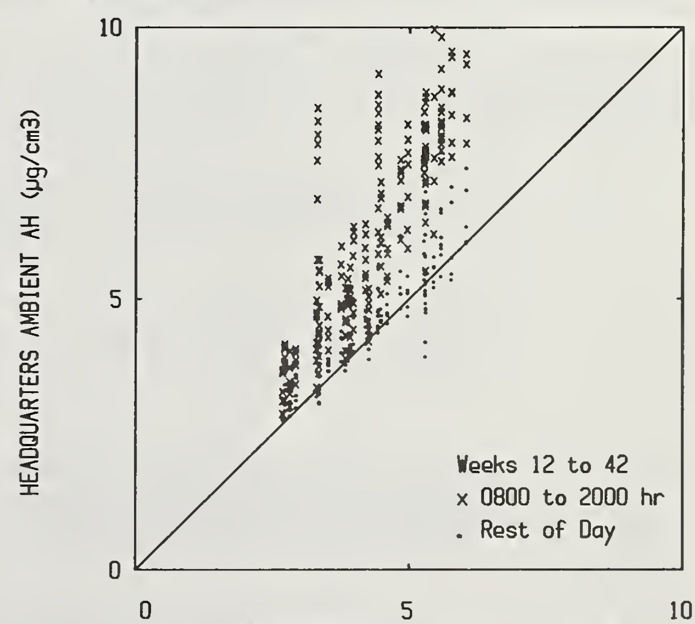

Fig. 6.—Comparison of diurnal ambient absolute humidity at the FEF Headquarters with the morning minimum ambient absolute humidity.

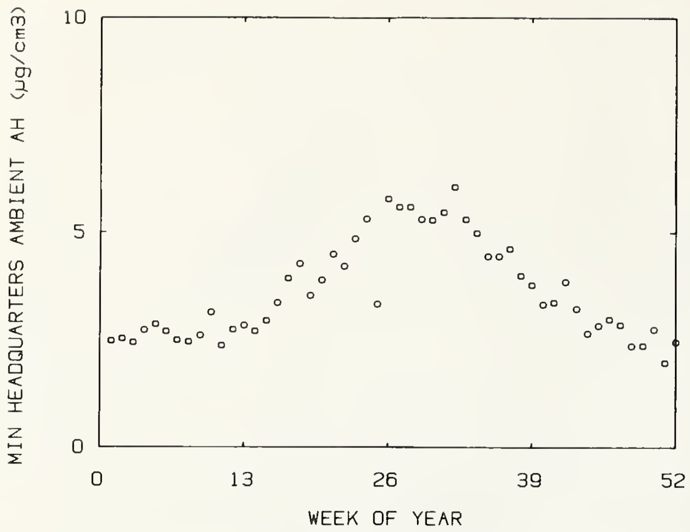

Fig. 7.—Four-year weekly mean minimum ambient absolute humidity at the FEF Headquarters weather station.

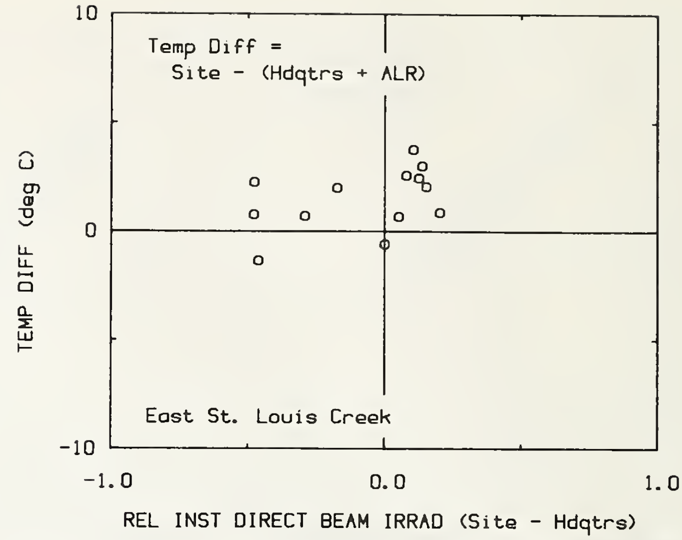

Fig. 9.—Comparison of the temperature difference between the canopy at 13 locations in East St. Louis Creek and the FEF Headquarters weather station temperature (adjusted for adiabatic effects) with the differences in relative instantaneous direct beam irradiance between each site and the FEF Headquarters.

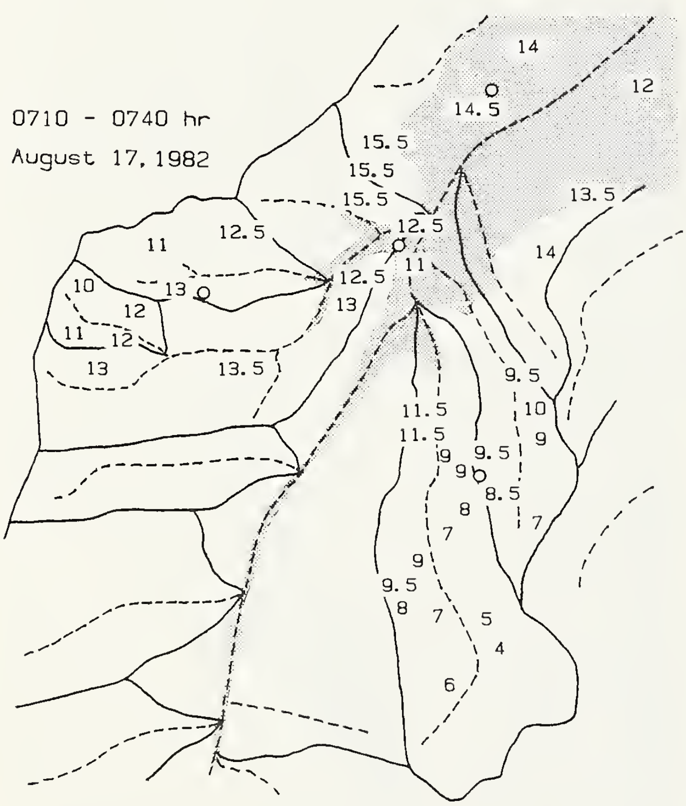

Fig. 8.—Canopy temperatures measured early in the day at various locations on the FEF with an IR thermometer mounted on a helicopter. The two temperatures indicated at the FEF Headquarters correspond to the beginning (top value) and end (bottom value) of the flight.

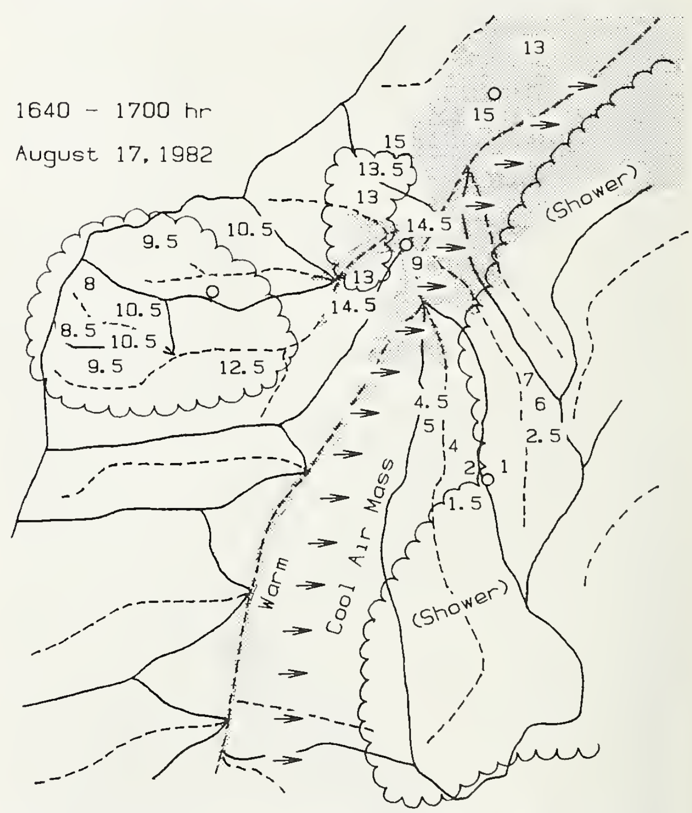

Fig. 10.—Canopy IR temperatures measured during a period of afternoon thundershowers. Cloud positions were determined from color video tapes. During the flight, a thunderstorm system and its associated cool air moved eastward, and the canopy IR temperature at the FEF Headquarters increased from 9 to 14.5° C as the system passed.

at the FEF Headquarters at the beginning of the flight was 9° C, and temperatures in East St. Louis and Fool Creeks were as low as 1.5° C. Forest canopies north and west of the FEF Headquarters were warmer even under a small cloud cover, and by the end of the flight, the FEF Headquarters IR temperature had increased to 14.5°C. Interestingly, the FEF Headquarters weather station air temperature remained at about 15.7° C throughout the

flight period, indicating that canopy temperatures responded far more rapidly than a protected hygrothermograph to changes in air mass temperature.

Using graphs similar to figure 9, the temperature differences between the FEF Headquarters weather station and the canopy in outlying areas around the Headquarters were determined at equivalent direct beam irradiances (e.g., temperature differences were determined for irradiance differences of 0.0). For example, the temperature differences between the East St. Louis Creek drainage and FEF Headquarters (adjusted for adiabatic lapse rate) at equivalent irradiances was +1.6° C for flight data shown in figure 9. The temperature range observed within watersheds was generally less than 3° to 5° C, after adjusting for adiabatic lapse rate. The temperature difference at equivalent irradiances was determined using the mean of adjusted temperatures, except when trends were apparent (e.g., fig. 9). In the latter case, lines fitted by least squares were used to determine the difference at the zero intercept of relative irradiance.

Values for the eight flights are given in table 1. Data for clear and cloudy conditions in the watershed units have been separated, and shaded areas (at low sun angles) are included with sunlit areas when the sky was clear. During the first flight of each day, when cold air drainage still affected temperature at the FEF Headquarters, canopy temperatures at the sites were uniformly higher than air temperature at the FEF Headquarters after adjusting for adiabatic effects. On later flights, however, temperatures differed greatly, with mean site temperatures under clear sky conditions as much as 3.0° C warmer and 4.3° C cooler than FEF Headquarters temperature. Under cloudy conditions, site temperatures were generally cooler, ranging from 1.5° C warmer to 11.7° C cooler than FEF Headquarters temperatures.

The mean difference between canopy temperature and FEF Headquarters weather station air temperature for clear and cloudy sky conditions is plotted for each flight in figure 11. Plotted values are the column means

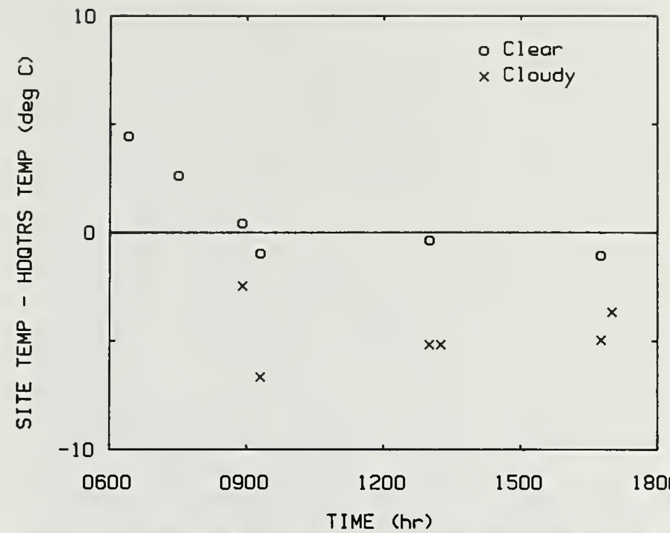

Fig. 11.—Diurnal pattern of the difference between canopy IR temperature and FEF Headquarters weather station air temperature (adjusted for adiabatic effects) for clear and cloudy conditions at canopy IR sites.

for clear or cloudy conditions in table 1. While the means obscure the wide, instantaneous local variation in canopy temperature, they provide an indication of the effect of cloud cover and the cooler air mass frequently associated with clouds on canopy temperature. Canopy temperatures early in the day under clear skies were warmer than FEF Headquarters temperatures adjusted for lapse rate effects; but by mid-morning, canopy temperatures were about 0.5° C cooler than FEF Headquarters temperatures. Cloudy conditions did not exist for either early flight; but in later flights under cloudy skies, the mean canopy temperature was 2° to 7° C cooler than FEF Headquarters temperatures. A possible bias in the data is considered below.

Discussion

The results are consistent with the hypothesis that, in high-elevation regions of the central Rocky Mountains,

Table 1.—Difference between canopy temperature for various areas of the FEF and air temperature (adjusted for adiabatic lapse rate) measured at the FEF Headquarters weather station. Temperature differences were calculated for equivalent irradiances. Times are at the midpoint of the flights which normally lasted about 40 minutes.

Watershed Units	Sky	July 13, 1982				August 17, 1982			
		0625 hr	0920 hr	1310 hr	1700 hr	0725 hr	0850 hr	1300 hr	1650 hr
East St. Louis Creek									
	clear	+5.3	—	—	—	+1.6	−3.7	−4.3	—
	cloudy	—	−6.7	−11.7	−8.7	—	—	−10.7	−9.3
Fool Creek									
	clear	+4.0	−1.0	—	—	+2.0	+3.0	0	—
	cloudy	—	—	−4.0	−6.0	—	−2.5	−8.0	−7.5
West St. Louis, Lexen, and Deadhorse Creeks									
	clear	+5.0	−0.5	—	—	+3.5	+1.5	—	−2.5
	cloudy	—	—	−3.0	0	—	—	−3.5	−2
Low-lying Areas									
	clear	+3.2	−1.6	—	—	+3.2	+1.0	+3.0	−1.0
	cloudy	—	—	−2.2	−0.2	—	—	+1.5	−1.5

air temperature and humidity are generally related to regional air mass phenomena. However, local phenomena, such as cold air drainage and thundershower activity, can produce pronounced effects. These results probably are applicable throughout the central Rocky Mountains during the summer months, because the area is dominated by a fairly stable high pressure system.

Much of the air temperature difference observed with elevation at the FEF was accounted for by dry adiabatic lapse rate effects. Thus, given suitable temperature observations at a site not influenced by cold air drainage, daytime and nighttime temperatures at different elevations could be predicted simply by adjusting for adiabatic effects. Many weather stations in mountainous regions are on valley floors, however, where they are subject to the effects of nocturnal cold air drainage. The prediction of higher elevation temperatures from valley weather stations must take into account the effects of cold air drainage.

At the FEF Headquarters weather station, cold air drainage reduced the nocturnal temperatures about 7° C. Greater or lesser effects may be observed in other locations, depending on the size of the upper watersheds, width of the valley floor, and specific location of the weather station. Another FEF weather station (Railroad weather station in fig. 1) was located 2 km northeast from the FEF Headquarters, at an elevation only 30 m below the Headquarters weather station but on a much wider floodplain. Weekly minimum temperatures for 1977 were 2.0° C higher at the Railroad weather station than at the FEF Headquarters, suggesting that the cold air drainage effect was more pronounced at the narrower portion of the floodplain found at the Headquarters area, where several watersheds converge. Daytime temperatures were similar at the two weather stations.

The effect of evening onset of cold air drainage on temperature at the FEF Headquarters was more variable than the morning termination. Mornings typically are clear or partly cloudy, except during periods of frontal activity, and solar irradiance increases rather predictably. Afternoons are often cloudy or partly cloudy, and clearing during the evening is irregular, making the evening pattern of radiation balance less uniform from day to day. Irregularity in the onset and duration of cold air drainage probably accounts for the high variability of temperatures between the high and low elevation weather stations during the transition hours (fig. 3).

While the mean elevational differences in temperature were influenced primarily by adiabatic and cold air drainage effects, differences in the daily pattern of absolute humidity at the lower elevation FEF Headquarters weather station appeared to be related to evapotranspiration. Midday increases in ambient absolute humidity observed at the FEF Headquarters occurred during the portion of the year when conditions were favorable for transpiration by the forest canopy (Kaufmann 1984b).

The general lack of ambient absolute humidity increases during the daytime at the higher elevations indicates that the air mass near the ground is continuously mixed with the air mass above the canopy, resulting in fairly stable absolute humidity throughout the day. Furthermore, cold air drainage apparently transports a portion of this air mass to the FEF Headquarters weather station, providing early morning minimum ambient absolute humidities very similar to the ambient humidity of the upper elevation air mass. The diurnal absolute humidity increases observed at the FEF Headquarters during the warmer months suggests that the air mass stagnates on the valley floor during midday.

The comparison of ambient absolute humidity among weather stations does not include a correction for the effects of elevation on pressure. Absolute humidity is a water vapor density term, and changes in pressure affect the density. The pressure differences between the FEF Headquarters weather station and the DH and WT weather stations are 4% and 6%, respectively, under standard atmosphere conditions (List 1971). Air subsidence from the upper weather stations to the FEF Headquarters station would result in an ambient absolute humidity increase of 4% to 6% under nonsaturated conditions, a change not detectable considering the natural variation in ambient absolute humidity (fig. 5) and the uncertainties in its measurement. For larger elevational differences, however, the effect of pressure on absolute humidity probably should be taken into account.

While adiabatic and cold air drainage effects resolve most of the elevational differences in mean air temperature, short-term, local canopy temperature differences during the daytime appear to be closely associated with clouds and thunderstorm activity. On several helicopter flights, data were collected on the fringes of eastward-moving thunderstorms. In the immediate vicinity of the storms, both the canopy surface temperature and the air mass temperature outside the helicopter were sharply reduced. Apparently, convective air movement drew cold upper-level air downward within the storm system. However, air and canopy temperatures rapidly increased again after the storm passed. These short-term events preclude the use of off-site weather data for temperature prediction for specific instances when convective activity exists, although average conditions may still be predicted using long-term weather record means.

Canopy temperatures under clear sky conditions were 0.5° to 1° C cooler during the day than predicted by FEF Headquarters conditions adjusted for adiabatic effects (fig. 11). It is likely that this temperature difference does not exist on average but is the result of a slight bias in data collecting. The decision to fly and collect IR temperature data was made at the FEF Headquarters area landing pad. Flights were begun when rainshowers appeared unlikely; but on several flights, conditions were poorer along the flight path than observed at the FEF Headquarters.

The conclusion that differences in direct beam irradiance associated with slope and aspect had little effect on canopy temperature is supported by several earlier reports. Furman (1978) found that aspect had little effect on the daily maximum temperature observed at a series of paired weather stations on either side of a for-

ested ridge, but the maximum temperature was strongly influenced by elevation. Oliver (1975) concluded from visual observations of smoke movement that air within the canopy of a pine forest moved freely, both in random horizontal and in vertical directions, as a result of convection. This air movement limits warming of foliage within the canopy.

Subalpine forest canopies are generally characterized by incomplete crown closure. Frequently, tree crowns are found in several layers, and substantial voids exist between trees at various levels within the canopy. Consequently, forced convection by the regional air mass probably prevents canopy temperatures from deviating significantly from air temperature above the canopy. Furthermore, any tendency for localized heating within portions of the canopy is counterbalanced by high aerodynamic conductance of the open, irregular canopy, favoring free convective heat loss. However, ground surface temperature may be influenced by irradiance, because mixing is substantially reduced near the surface. In contrast to subalpine forests, heating was observed during midday within the canopy of a very dense loblolly pine stand in need of thinning (Hosker et al. 1974).

In summary, mean air and canopy temperatures varied predictably with elevation as a result of adiabatic effects. However, local temperatures differed greatly during thunderstorm activity or beneath clouds. Different levels of direct beam irradiance associated with slope and aspect had little effect on canopy temperature. Nocturnal cold air drainage affected valley air temperatures, but the cold air drainage also permitted the estimation of upper elevation ambient absolute humidity from measurements of the minimum valley absolute humidity measured during the cold air drainage period.

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Keywords: Air temperature, canopy temperature, elevation, slope, aspect, irradiance, absolute humidity, cold air drainage, adiabatic lapse rate, subalpine forests, subalpine watersheds.

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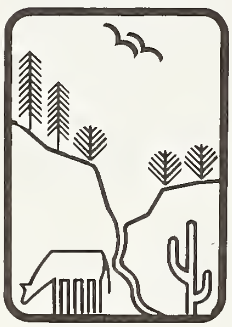
Rocky Mountains



Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

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